OPTICAL TRANSMISSION SYSTEM, OPTICAL MULTIPLEXER, AND OPTICAL DEMULTIPLEXER

BACKGROUND OF THE INVENTION

5   Field of the Invention

The present invention relates to an optical transmission system that transmits a signal lightwave comprising a plurality of component signals each having a different wavelength, an optical multiplexer for combining component signals each having a different wavelength to constitute a signal lightwave,

10   and an optical demultiplexer for separating a plurality of component signals each having a different wavelength from a signal lightwave.

Description of the Background Art

The wavelength division multiplexing (WDM) optical transmission system multiplexes a plurality of component signals to transmit them over one optical

15   fiber transmission line. The WDM optical transmission system can transmit and receive a large volume of information over one optical fiber. For trunk-line optical transmission systems for which communication demands are booming, researchers and engineers are studying to increase the transmission capacity further by increasing the degree of multiplexing through the narrow-

20   ing of the wavelength spacing of the component signals. A WDM transmission system having a high degree of multiplexing is known as a dense WDM (DWDM) system.

Published Japanese patent application 2000-156702 (corresponding pub-

lished European patent application: EP 0991217A2) has disclosed an invention that relates to a low-cost WDM system having a wide wavelength spacing of the component signals. Such a system is called a coarse WDM (CWDM) system, which is usually used for a relatively low volume of communication traffic.

5 The CWDM optical transmission system has a small number of optical parts, such as signal light sources and light-receiving devices, because it has a small number of component signals. Its wide wavelength spacing of the component signals enables the use of low-cost optical parts, such as optical multiplexers and optical demultiplexers, having low wavelength precision. As a result, a

10 low-cost system can be constructed.

In the CWDM optical transmission system, however, the wide wavelength spacing of the component signals broadens the total wavelength band of a signal lightwave comprising a plurality of component signals. The band width is sometimes broadened to about 100 nm. When the wavelength band has a

15 width of about 100 nm, the optical fiber transmission line has a large difference in transmission loss between an extremely shorter wavelength and an extremely longer wavelength in the band. Consequently, powers of the component signals arriving at the optical receiver differ largely with one another. The difference can be eliminated nearly completely by using an optical ampli-

20 fier equipped with a gain equalizer. However, the CWDM optical transmission system must be constructed at a low-cost without using the optical amplifier. Therefore, the CWDM optical transmission system has difficulty in transmitting with high quality all the component signals in the total wave-

length band of a signal lightwave.

SUMMARY OF THE INVENTION

An object of the present invention is to offer an optical transmission system

5   suitable for the CWDM optical transmission, particularly an optical transmis-

sion system capable of transmitting with high quality all the component signals

each having a different wavelength in a broad band.   Another object is to offer

an optical multiplexer and an optical demultiplexer to be used in the optical

transmission system.

10   According to the present invention, the foregoing object is attained by offer-

ing the following optical transmission system for transmitting a signal light-

wave comprising a plurality of component signals each having a different

wavelength.   The optical transmission system comprises:

(a) at least one optical transmitter;

15   (b) at least one optical receiver;

(c) an optical fiber transmission line that is installed between the at least

one optical transmitter and the at least one optical receiver; and

(d) an optical component that:

(d1) is installed between the at least one optical transmitter and the at

20   least one optical receiver; and

(d2) gives a loss to the signal lightwave.

The component signals include a component signal having a wavelength of λ_a

and a component signal having a wavelength of λ_b. The optical transmission

system is designed such that:

(e) the total transmission loss in the optical fiber transmission line is smaller at a wavelength of λ_b than at a wavelength of λ_a

(f) the insertion loss of the optical component is larger at a wavelength of λ_b

5   than at a wavelength of λ_a and

(g) the difference in power between the component signal having a wavelength of λ_a arriving at the at least one optical receiver and the component signal having a wavelength of λ_b arriving at the at least one optical receiver is smaller than the difference in the total transmission loss in the optical fi-

10   ber transmission line between the wavelengths λ_a and λ_b.

The foregoing optical component may be an optical multiplexer, an optical demultiplexer, or a variable attenuator. The length of the optical transmission line may be at most 150 km.

According to one aspect of the present invention, the present invention offers

15   the following optical multiplexer for combining a plurality of component signals each having a different center wavelength to constitute a signal lightwave. The optical multiplexer has an insertion loss that increases with increasing center wavelength of the component signals.

According to another aspect of the present invention, the present invention

20   offers the following optical demultiplexer for separating a plurality of component signals each having a different center wavelength from a signal lightwave. The optical demultiplexer has an insertion loss that increases with increasing center wavelength of the component signals.

According to yet another aspect of the present invention, the present invention offers the following optical multiplexer for combining a plurality of component signals each having a different center wavelength to constitute a signal lightwave. The optical multiplexer has an insertion loss-center wavelength property that has a tendency reciprocal to that of the loss-wavelength property of the optical transmission line of the optical transmission system into which the optical multiplexer is incorporated.

According to yet another aspect of the present invention, the present invention offers the following optical demultiplexer for separating a plurality of component signals each having a different center wavelength from a signal lightwave. The optical demultiplexer has an insertion loss-center wavelength property that has a tendency reciprocal to that of the loss-wavelength property of the optical transmission line of the optical transmission system into which the optical demultiplexer is incorporated.

According to yet another aspect of the present invention, the present invention offers the following optical multiplexer for combining a plurality of component signals each having a different center wavelength to constitute a signal lightwave. The optical multiplexer is incorporated into an optical transmission system that comprises an optical demultiplexer and at least one optical receiver. The optical multiplexer has an insertion loss-center wavelength property that has a tendency similar to that of the signal power-center wavelength property of the component signals arriving at the at least one optical receiver when the insertion losses of the optical multiplexer and demultiplexer

are excluded.

According to yet another aspect of the present invention, the present invention offers the following optical demultiplexer for separating a plurality of component signals each having a different center wavelength from a signal light-

5   wave. The optical demultiplexer is incorporated into an optical transmission system that comprises an optical multiplexer and at least one optical receiver. The optical demultiplexer has an insertion loss-center wavelength property that has a tendency similar to that of the signal power-center wavelength property of the component signals arriving at the at least one optical receiver when

10   the insertion losses of the optical multiplexer and demultiplexer is excluded.

The present invention is further explained below by referring to the accompanying drawings. The drawings are provided solely for the purpose of illustration and are not intended to limit the scope of the invention.

15   BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a diagram showing the constitution of an optical transmission system 1 in the first embodiment of the optical transmission system of the present invention.

Figures 2A and 2B are diagrams showing the transition of the power of indi-

20   vidual component signals from the optical transmitter to the optical receiver in the optical transmission system 1.

Figure 3 is a diagram showing the constitution of an optical transmission system 2 in the second embodiment of the optical transmission system of the

present invention.

Figures 4A to 4D are diagrams illustrating the following properties in the optical transmission system 1: the transmission loss of the optical fiber transmission line, the insertion loss of the optical multiplexer and the optical demultiplexer, and the power of individual component signals arriving at the optical receiver.

Figure 5 is a diagram showing the constitution of an optical transmission system in Example 1.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention are explained below by referring to the accompanying drawings. In the drawings, the same number or sign refers to the same element to avoid duplicated explanation. The ratios of the dimensions in the drawings do not necessarily coincide with the explanation.

The first embodiment of the optical transmission system of the present invention is explained below by referring to Fig. 1. In Fig. 1, an optical transmission system 1 comprises optical transmitters 11_1 to 11_N, an optical multiplexer 12, an optical fiber transmission line 20, an optical demultiplexer 32, and optical receivers 31_1 to 31_N. The letter "N" denotes the total number of component signals, optical transmitters, or optical receivers, and is an integer larger than one. No optical amplifier is provided between the optical transmitters 11_1 to 11_N and the optical receivers 31_1 to 31_N.

Component signals having mutually different wavelengths of λ_1 to λ_N out-

putted from the optical transmitters 11_1 to 11_N are combined by the optical multiplexer 12, travel over the optical fiber transmission line 20, and arrive at the optical demultiplexer 32. The combined component signals are separated by the optical demultiplexer 32 according to their wavelengths. The component signal having a wavelength of λ_n is received by the optical receiver 31_n. The suffix "n" indicates n-th in order of an individual component signal, optical transmitter, or optical receiver in the total number N.

In the optical transmission system 1, when the component signal having a wavelength of λ_n travels from the optical transmitter 11_n to the optical receiver 31_n, it suffers a loss of α_n (dB), which is expressed by formula (1).

$$\alpha_n = \alpha_{1,n} + \alpha_{2,n} + \alpha_{3,n} \qquad ...(1),$$

where

$\alpha_{1,n}$: insertion loss (dB) of the optical multiplexer 12

$\alpha_{2,n}$: total transmission loss (dB) in the optical fiber transmission line 20

$\alpha_{3,n}$: insertion loss (dB) of the optical demultiplexer 32.

When a component signal having a wavelength of λ_n is outputted from the optical transmitter 11_n and it has a fixed power of P_0 (dBm) without regard to its wavelength, the component signal arriving at the optical receiver 31_n has a power of P_n (dBm), which is expressed by formula (2).

$$P_n = P_0 - \alpha_n \qquad ...(2).$$

In the optical transmission system 1, the optical fiber transmission line 20 has a length of at most 150 km, which is the maximum transmission length of an practical optical transmission system without an optical fiber amplifier, and

the system is designed such that any two wavelengths λ_a and λ_b in the wavelength range of λ_1 to λ_N produce relationships expressed by formulae (3a) to (3b).

$$\alpha_{2,a} > \alpha_{2,b} \qquad \ldots(3a).$$

$$\alpha_{1,a} < \alpha_{1,b} \qquad \ldots(3b).$$

$$\alpha_{3,a} < \alpha_{3,b} \qquad \ldots(3c).$$

In addition, $\alpha_{2,a}$, $\alpha_{2,b}$, P_a, and P_b have a relationship expressed by formula (4).

$$|\alpha_{2,a} - \alpha_{2,b}| > |P_a - P_b| \qquad \ldots(4).$$

The optical transmission system 1 designed by the above-described manner can transmit all the component signals with high quality even when a signal light-wave has a broad total wavelength band. Therefore, the system is suitable for the CWDM optical transmission.

The system is advantageous in that it has no optical amplifier between the optical transmitters 11_1 to 11_N and the optical receivers 31_1 to 31_N, and therefore the power of a signal lightwave decreases monotonously. As a result, the optical transmission system 1 can be constructed at low cost with high reliability.

Any wavelength in the wavelength range of λ_1 to λ_N may be at most 1,520 nm, and any other wavelength may be at least 1,570 nm. Each component signal may have a band width of at least 20 nm. The wavelength spacing of the component signals may be at least 10 nm. As explained above, even when the optical fiber transmission line 20 has a large variation in transmission loss because of the broad total wavelength band of the signal lightwave or because

of the wide wavelength spacing of the component signals, the optical transmission system 1 can minimize the variation in the power of the individual component signals arriving at the optical receiver.

It is desirable to transmit the signals at a rate of at most 10 Gb/s. In this case, the optical transmission system 1 can transmit the signal lightwaves with high quality without relying on means for compensating the chromatic dispersion. Consequently, the optical transmission system 1 can be constructed at low cost. It is desirable that the optical fiber transmission line 20 have a transmission loss of at most 0.4 dB/km at a wavelength of 1.38 μm. In this case, a signal lightwave having a wavelength of 1.38 μm or so can also be used.

It is desirable that the optical receivers 31_1 to 31_N comprise an avalanche photodiode. In this case, the increased signal-receiving sensitivity of the optical receivers 31_1 to 31_N can ensure a sufficient margin in the system design and extend the transmission distance of the signal lightwave. It is desirable that the optical receivers 31_1 to 31_N comprise a PIN photodiode. In this case, the optical receivers 31_1 to 31_N can be constructed at low cost, and consequently the construction cost for the optical transmission system 1 can be reduced.

Figures 2A and 2B are diagrams showing the transition of the power of a component signal having a wavelength of λ_a and another component signal having a wavelength of λ_b from the optical transmitter to the optical receiver in an optical transmission system. Figure 2B is a diagram for the first embodiment. Figure 2A is a diagram for a comparative example for which the greater-than sign (>) in formula (3a) is unchanged, and the less-than signs (<)

in formulae (3b) and (3c) are changed to greater-than signs. In Figs. 2A and 2B, the solid line shows the transition of the power of a component signal having a wavelength of λ_a, and the broken line shows that of a component signal having a wavelength of λ_b.

5   The component signal having a wavelength of λ_a is outputted from an optical transmitter 11_a with a power of P_0. It suffers a loss of $\alpha_{1,a}$ at a position X where the optical multiplexer is located. It suffers a loss of $\alpha_{2,a}$ in the optical fiber transmission line. It suffers a loss of $\alpha_{3,a}$ at a position Y where the optical demultiplexer is located. It arrives at the optical receiver 31_a with a power of P_a.

10   Similarly, the component signal having a wavelength of λ_b is outputted from an optical transmitter 11_b with a power of P_0. It suffers a loss of $\alpha_{1,b}$ at a position X. It suffers a loss of $\alpha_{2,b}$ in the optical fiber transmission line. It suffers a loss of $\alpha_{3,b}$ at a position Y. It arrives at the optical receiver 31_b with a power of P_b.

15   As can be seen from Fig. 2A for the comparative example, as the signal lightwave travels from the optical transmitter to the optical receiver, the difference in power between the component signal having a wavelength of λ_a and the component signal having a wavelength of λ_b increases. On the other hand, in Fig. 2B for the first embodiment, as the signal lightwave travels from the optical transmitter toward the optical receiver, the position X produces a difference in power between the component signal having a wavelength of λ_a and the component signal having a wavelength of λ_b. The difference, however, de-

creases as the signal lightwave travels over the optical fiber transmission line 20. Then, the magnitudes of the power of the two component signals are reversed at some midpoint in the transmission line 20. At the point Y, the difference in the power becomes smaller than the difference between $\alpha_{2,a}$ and $\alpha_{2,b}$. This result satisfies the relationship expressed by formula (4) above.

As described above, the comparative example and the first embodiment perform differently. In the comparative example, the power P_a of the component signal having a wavelength of λ_a at the time of the arrival at the optical receiver 31_a is smaller than the receiving sensitivity P_{th} of the optical receiver 31_a. On the other hand, in the first embodiment, the power P_a is larger than the receiving sensitivity P_{th}.

The performance difference is explained more specifically in the following example. In this example, both the comparative example and the first embodiment have an optical fiber transmission line comprising a single-mode optical fiber with a zero dispersion wavelength at a wavelength of 1.3 μm or so. The transmission line has a length of 150 km. The signal-transmitting rate is 2.5 Gb/s. Two component signals are transmitted with wavelengths of $\lambda_a = 1.45$ μm and $\lambda_b = 1.55$ μm. The magnitude of $\alpha_{2,a}$ is 0.26 dB/km, and that of $\alpha_{2,b}$ is 0.20 dB/km. The optical receivers 31_a and 31_b comprise an avalanche photodiode and have a receiving sensitivity, P_{th}, of -34 dBm (BER = 10^{-9}). The optical transmitters 11_a and 11_b output the component signals having a power, P_0, of 7 dBm.

The comparative example has a feature of $\alpha_{1,a} = 1.5$ dB, $\alpha_{1,b} = 0.5$ dB, $\alpha_{3,a} =$

1.5 dB, and $\alpha_{3,b}$ = 0.5 dB. In this case, the power P_a of the component signal having a wavelength of λ_a becomes -35 dBm when the signal arrives at the optical receiver 31_a. Similarly, the power P_b becomes -24 dBm. Because of $P_a <$ P_{th}, the receiving errors occur frequently. On the other hand, the first em-

5   bodiment has a feature of $\alpha_{1,a}$ = 0.5 dB, $\alpha_{1,b}$ = 1.5 dB, $\alpha_{3,a}$ = 0.5 dB, and $\alpha_{3,b}$ = 1.5 dB. In this case, the power P_a becomes -33 dBm, and the power P_b becomes -26 dBm. Because of $P_a > P_{th}$ and $P_b > P_{th}$, the frequency of occurrence of the receiving errors is sufficiently small. As explained above, the first embodi-ment can transmit with high quality all the component signals each having a

10   different wavelength even when the signal lightwave has a broad total wave-length band. Therefore, it is suitable for the CWDM optical transmission.

The second embodiment of the optical transmission system of the present invention is explained below by referring to Fig. 3. An optical transmission system 2 comprises optical fiber transmission lines 21 to 23, an optical multi-

15   plexer 13, an optical fiber transmission line 20, a variable attenuator 40, an optical demultiplexer 32, and optical receivers 31_1 to 31_N, where "N" denotes an integer larger than one. Although not shown in Fig. 3, the optical transmis-sion system 2 further comprises a plurality of optical transmitters connected to the optical fiber transmission lines 21 to 23. An optical network may be struc-

20   tured between the optical transmitters and the optical multiplexer 13. No optical amplifier is provided between the optical transmitters and the optical receivers 31_1 to 31_N to amplify signal lightwaves.

Component signals having mutually different wavelengths of λ_1 to λ_N

14

transmitted over the optical fiber transmission lines 21 to 23 are combined by the optical multiplexer 13. The combined component signals travel over the optical fiber transmission line 20, suffer a loss given by the variable attenuator 40 according to their wavelengths, and arrive at the optical demultiplexer 32.

5   The combined component signals are separated by the optical demultiplexer 32 according to their wavelengths. The component signal having a wavelength of λ_n is received by the optical receiver 31_n. No component signal having a wavelength of λ_n outputted from one of the optical transmitters is amplified until it arrives at the optical receiver 31_n.

10   In the optical transmission system 2, when the component signal having a wavelength of λ_n travels from the optical transmitter to the optical receiver 31_n, it suffers a loss of α_n (dB), which is expressed by formula (5).

$$\alpha_n = \alpha_{1,n} + \alpha_{2,n} + \alpha_{3,n} + \alpha_{4,n} \qquad ...(5),$$

where

15   $\alpha_{1,n}$: insertion loss (dB) of the optical multiplexer 13 for a wavelength of λ_n

$\alpha_{2,n}$: total transmission loss (dB) in one of the optical fiber transmission lines 21 to 23 and the optical fiber transmission line 20 for a wavelength of λ_n

$\alpha_{3,n}$: insertion loss (dB) of the optical demultiplexer 32 for a wavelength of λ_n

20   $\alpha_{4,n}$: insertion loss (dB) of the variable attenuator 40 for a wavelength of λ_n.

When the component signal with a wavelength of λ_n outputted from the optical transmitter has a fixed power of P_0 (dBm), the component signal with a wave-

length of λ_n arriving at the optical receiver 31_n has a power of P_n (dBm), which is expressed by formula (2) above.

In the optical transmission system 2, the total length of one of the optical fiber transmission lines 21 to 23 and the optical fiber transmission line 20 is at most 150 km, and the system is designed such that any two wavelengths λ_a and λ_b in the wavelength range of λ_1 to λ_N produce relationships expressed by formulae (6a) to (6d).

$$\alpha_{2,a} > \alpha_{2,b} \qquad ...(6a).$$

$$\alpha_{1,a} < \alpha_{1,b} \qquad ...(6b).$$

$$\alpha_{3,a} < \alpha_{3,b} \qquad ...(6c).$$

$$\alpha_{4,a} < \alpha_{4,b} \qquad ...(6d).$$

In addition, the difference in power between the component signal with a wavelength λ_a arriving at the optical receiver 31_a and the component signal with a wavelength λ_b arriving at the optical receiver 31_b is smaller than the difference in total transmission loss in the optical fiber transmission line 20 between the wavelengths λ_a and λ_b. This condition satisfies the relationship expressed by formula (4) above. The optical transmission system 2 designed by the above-described manner can transmit all the component signals having mutually different wavelengths with high quality even when the signal light-wave has a broad total wavelength band.   Therefore, the system is particularly suitable for the CWDM optical transmission.

The system is advantageous in that it has no optical amplifier between the

optical transmitters and the optical receivers 31_1 to 31_N, and therefore the power of the signal lightwave decreases monotonously. As a result, the optical transmission system 2 can be constructed at low cost with high reliability. Any wavelength in the wavelength range of λ_1 to λ_N may be at most 1,520 nm, and any other wavelength may be at least 1,570 nm. Each component signal may have a band width of at least 20 nm. The wavelength spacing of the component signals may be at least 10 nm. As explained above, even when the optical fiber transmission line 20 has a large variation in transmission loss because of the broad total wavelength band of the signal lightwave or because of the wide wavelength spacing of the component signals, the optical transmission system 2 can minimize the variation in the power of the individual component signals arriving at the optical receiver.

It is desirable to transmit the signals at a rate of at most 10 Gb/s. In this case, the optical transmission system 2 can transmit the signal lightwaves with high quality without relying on means for compensating the chromatic dispersion. Consequently, the optical transmission system 2 can be constructed at low cost. It is desirable that the optical fiber transmission line 20 have a transmission loss of at most 0.4 dB/km at a wavelength of 1.38 μm. In this case, a signal lightwave having a wavelength of 1.38 μm or so can also be used.

It is desirable that the optical receivers 31_1 to 31_N comprise an avalanche photodiode. In this case, the increased signal-receiving sensitivity of the optical receivers 31_1 to 31_N can ensure a sufficient margin in the system design and extend the transmission distance of the signal lightwave. It is desirable that

the optical receivers 31_1 to 31_N comprise a PIN photodiode. In this case, the optical receivers 31_1 to 31_N can be constructed at low cost, and consequently the construction cost for the optical transmission system 2 can be reduced.

It is desirable that the variable attenuator 40 be placed at a place posterior to the optical multiplexer 13 and anterior to the optical demultiplexer 32. In this case, the variable attenuator 40 can control the loss of all the component signals (the number of component signals is N). Therefore, the optical transmission system 2 can be constructed at low cost. It is desirable that the variable attenuator 40 have a variable wavelength property. In this case, the variable attenuator 40 can properly respond to a situation in which the transmission loss between the optical transmitters and the optical multiplexer 13 varies with wavelength.

Embodiments of the optical multiplexer and the optical demultiplexer of the present invention are explained below. They can be used suitably as the optical multiplexers 12 and 13 and the optical demultiplexer 32 incorporated into the optical transmission systems 1 and 2.

In the following explanation, the optical multiplexer 12 and the optical demultiplexer 32 are used as an example. Figure 4A shows a wavelength dependence of the transmission loss of the optical fiber transmission line 20. Figure 4B shows an example of the wavelength dependence of the insertion loss of the optical multiplexer 12 and the optical demultiplexer 32. Figure 4C shows the power of individual component signals with mutually different wavelengths arriving at the optical receiver when the insertion loss of the opti-

cal multiplexer 12 and the optical demultiplexer 32 does not vary with wavelength. Figure 4D shows the power of individual component signals with mutually different wavelengths arriving at the optical receiver when the insertion loss of the optical multiplexer 12 and the optical demultiplexer 32 varies with

5 wavelength.

As shown in Fig. 4A, the transmission loss of the optical fiber transmission line 20 has a minimum value at a wavelength of 1.55 μm or so. In a wavelength region of less than 1.55 µm, the transmission loss decreases with increasing wavelength. Consequently, when the insertion loss of the optical

10 multiplexer 12 and the optical demultiplexer 32 does not vary with wavelength, the power of component signals arriving at the optical receiver increases with increasing wavelength in a wavelength region of less than 1.55 µm as shown in Fig. 4C.

On the other hand, as shown in Fig. 4B, when the system incorporates the

15 optical multiplexer 12 or the optical demultiplexer 32 whose insertion loss increases as the center wavelength for the multiplexing and demultiplexing increases, the wavelength dependence of the power of the component signals arriving at the optical receiver can be reduced as shown in Fig. 4D. As a result, the system can transmit all the component signals with high quality even when

20 the signal lightwave has a broad total wavelength band. Therefore, the system is suitable for the CWDM optical transmission. Furthermore, the system is advantageous in that it is easy to design, it has superior productivity, it can be constructed at low cost, and it has good applicability as a system.

In addition, when the loss-wavelength property of the optical multiplexer or the optical demultiplexer is designed to compensate or flatten the loss-wavelength property of the optical transmission line or the entire system, additional components can be eliminated and therefore an increase in the system

5   construction cost can be suppressed. Furthermore, the loss budget of the channels at the shorter-wavelength region can be improved, and consequently the reliability of the system can be increased.

It is desirable that the center-wavelength spacing of the component signals to be combined or separated by the optical multiplexer 12 or the optical demulti-

10   plexer 32 be at least 10 nm. It is desirable that any of the component signals to be combined or separated have a center wavelength of at most 1,520 nm and any other component signal have a center wavelength of at least 1,570 nm. Alternatively, it is desirable that any of the component signals to be combined or separated have a center wavelength of at most 1,410 nm and any other com-

15   ponent signal have a center wavelength of at least 1,570 nm. Yet alternatively, it is desirable that any of the component signals to be combined or separated have a center wavelength of at most 1,310 nm and any other component signal have a center wavelength of at least 1,590 nm. As described above, even when the signal lightwave has a broad total wavelength band or the component sig-

20   nals have a wide center-wavelength spacing, the optical transmission system 2 can reduce the variation in the transmission loss in the optical fiber transmission line over the entire wavelength band of the signal lightwave.

When any of the component signals to be combined or separated has a center

wavelength of at most 1,520 nm and any other component signal has a center wavelength of at least 1,570 nm, the transmission loss in the optical fiber transmission line 20 is small and the light source in the optical transmitter is less costly. When any of the component signals to be combined or separated

5 has a center wavelength of at most 1,410 nm and any other component signal has a center wavelength of at least 1,570 nm, the system can effectively utilize the wavelength region that is less susceptible to the direct influence of the OH group-induced loss. When any of the component signals to be combined or separated has a center wavelength of at most 1,310 nm and any other compo-

10 nent signal has a center wavelength of at least 1,590 nm, the system can effectively utilize the broadest entire low-loss wavelength region of the optical fiber transmission line 20.

Specific examples are explained below. Example 1 employs an optical transmission system having the structure shown in Fig. 5. As shown in Fig. 5,

15 the component signals (the number of component signals is "N") outputted from optical transmitters 11_1 to 11_N are combined by an optical multiplexer 12 to travel over an optical fiber transmission line 20. They pass through a band-pass filter 50 and arrive at an optical receiver 31. In Example 1, the number of component signals is four. They have a wavelength of 1,510 to 1,570 nm

20 with a spacing of 20 nm. The optical fiber transmission line 20 is composed of a single-mode optical fiber with a length of 50 km.

Table I shows losses of the components such as the optical multiplexer used in Example 1. In the wavelength range of 1,510 to 1,570 nm, the total trans-

mission loss of the optical fiber transmission line 20 has a variation range of 0.9

dB (the term "variation range" is used to mean the difference between the lar-

gest and the smallest in a set of numbers). However, this system uses an opti-

cal multiplexer 12 whose insertion loss increases with increasing wavelength.

5   As a result, the variation range of the total loss is reduced to 0.2 dB.

Table I

Wavelength (nm)	Loss (dB) (optical fiber)	Loss (dB) (multiplexer)	Loss (dB) (total)
1510	10.7	0.4	11.1
1530	10.3	0.7	11.0
1550	10.0	1.0	11.0
1570	9.8	1.4	11.2
Variation range	0.9	-	0.2

Example 2 employs an optical transmission system having the structure

10   shown in Fig. 1. In Example 2, the number of component signals is nine.

They have a wavelength of 1,410 to 1,570 nm with a spacing of 20 nm. The

optical fiber transmission line 20 is composed of a non-zero dispersion-shifted

optical fiber with a length of 50 km. Table II shows losses of the components

such as the optical multiplexer used in Example 2. In the wavelength range of

15   1,410 to 1,570 nm, the total transmission loss of the optical fiber transmission

line 20 has a variation range of 3.7 dB. However, this system uses an optical

multiplexer 12 and an optical demultiplexer 32 whose insertion losses increase

with increasing wavelength. As a result, the variation range of the total loss

is reduced to 1.6 dB.

20

Table II

Wavelength (nm)	Loss (dB) (optical fiber)	Loss (dB) (multiplexer)	Loss (dB) (demultiplexer)	Loss (dB) (total)
1410	13.2	0.3	0.3	13.8
1430	12.3	0.7	0.7	13.7
1450	11.6	1.1	1.2	13.9
1470	11.0	1.4	1.5	13.9
1490	10.5	1.7	1.9	14.1
1510	10.1	1.9	2.3	14.3
1530	9.8	2.1	2.7	14.6
1550	9.6	2.3	3.0	14.9
1570	9.5	2.5	3.3	15.3
Variation range	3.7	-	-	1.6

Example 3 employs an optical transmission system having the structure shown in Fig. 1. In Example 3, the number of component signals is 16. They have a wavelength of 1,310 to 1,610 nm with a spacing of 20 nm. The optical fiber transmission line 20 is composed of a single-mode optical fiber with a length of 100 km. The optical fiber has a suppressed OH group-induced loss at a wavelength of 1.38 μ m. Table III shows losses of the components such as the optical multiplexer used in Example 3. In the wavelength range of 1,310 to 1,610 nm, the total transmission loss of the optical fiber transmission line 20 has a variation range of 14.2 dB. However, the use of the optical multiplexer 12 and the optical demultiplexer 32 reduces the variation range of the total loss to 6.3 dB. In this case, the loss-wavelength property of the optical multiplexer 12 and the optical demultiplexer 32 is adjusted in accordance with that of the total transmission loss of the optical fiber transmission line 20. This adjusting method can further reduce the variation range of the total loss in comparison with the case where the insertion loss varies monotonously with wave-

length.

Table III

Wavelength (nm)	Loss (dB) (optical fiber)	Loss (dB) (multiplexer)	Loss (dB) (demultiplexer)	Loss (dB) (total)
1310	33.1	0.3	0.3	33.7
1330	31.4	0.6	0.8	32.8
1350	29.9	0.9	1.2	32.0
1370	29.2	1.2	1.6	31.9
1390	28.8	1.5	2.0	32.3
1410	26.4	1.9	2.4	30.7
1430	24.7	2.2	2.7	29.6
1450	23.2	2.5	2.9	28.6
1470	22.1	2.8	3.2	28.1
1490	21.1	3.1	3.6	27.8
1510	20.2	3.3	3.9	27.4
1530	19.6	3.7	4.3	27.5
1550	19.2	4.0	4.6	27.8
1570	18.9	4.5	5.1	28.5
1590	19.1	4.3	4.9	28.3
1610	19.8	3.5	4.1	27.4
Variation range	14.2	-	-	6.3

5   Example 4 employs an optical transmission system having the structure shown in Fig. 5. In Example 4, the number of component signals is six. They have a wavelength of 1,510 to 1,560 nm with a spacing of 10 nm. The optical fiber transmission line 20 is composed of a dispersion-shifted optical fiber with a length of 50 km. Example 4 uses an optical multiplexer 12 whose insertion

10   loss increases with increasing wavelength. Its comparative example uses an optical multiplexer whose insertion loss varies randomly without regard to wavelength. Table IV shows losses of the components such as the optical multiplexer used in Example 4 and the comparative example. In the wavelength

range of 1,510 to 1,560 nm, the total transmission loss of the optical fiber
transmission line 20 has a variation range of 0.55 dB.   In the comparative
example, which uses an optical multiplexer whose insertion loss varies ran-
domly without regard to wavelength, the variation range of the total loss in-
5   creases to 1.4 dB.   On the other hand, in Example 4, which uses the optical
multiplexer 12 whose insertion loss increases with increasing wavelength, the
variation range of the total loss is 1.1 dB.

Table IV

Wave-length (nm)	Loss (dB) (optical fiber)	Example 4		Comparative example	
		Loss (dB) (multi-plexer)	Loss (dB) (total)	Loss (dB) (multi-plexer)	Loss (dB) (total)
1510	10.08	0.32	10.4	0.62	10.7
1520	9.93	0.64	10.6	0.91	10.8
1530	9.77	1.02	10.8	0.3	10.1
1540	9.69	1.32	11.0	1.18	10.9
1550	9.60	1.70	11.3	1.92	11.5
1560	9.53	1.98	11.5	1.46	11.1
Variation range	0.55	-	1.1	-	1.4

10

Example 5 employs an optical transmission system having the structure
shown in Fig. 5.   In Example 5, the number of component signals is six.   They
have a wavelength of 1,520 to 1,545 nm with a spacing of 5 nm.   The optical
fiber transmission line 20 is composed of a dispersion-shifted optical fiber with
15   a length of 50 km. Example 5 uses an optical multiplexer 12 whose insertion
loss increases with increasing wavelength.   Its comparative example uses an
optical multiplexer whose insertion loss varies randomly without regard to

wavelength. Table V shows losses of the components such as the optical multiplexer used in Example 5 and the comparative example. In the wavelength range of 1,520 to 1,545 nm, the total transmission loss of the optical fiber transmission line 20 has a variation range of 0.29 dB. In the comparative

5 example, which uses an optical multiplexer whose insertion loss varies randomly without regard to wavelength, the variation range of the total loss increases to 1.4 dB. In Example 5, which uses the optical multiplexer 12 whose insertion loss increases with increasing wavelength, the variation range of the total loss is also 1.4 dB. In Example 5, the component signals have a narrow

10 wavelength spacing. In such a case, the wavelength dependence of the transmission loss of the optical fiber transmission line 20 is much smaller than that of the insertion loss of the optical multiplexer in many instances. The same can be said in Example 5 as shown in Table V. As a result, Example 5 and the comparative example have a similar variation range of the total loss.

15

Table V

Wave-length (nm)	Loss (dB) (optical fiber)	Example 5		Comparative example	
		Loss (dB) (multi-plexer)	Loss (dB) (total)	Loss (dB) (multi-plexer)	Loss (dB) (total)
1520	9.93	0.28	10.2	0.66	10.6
1525	9.85	0.54	10.4	0.93	10.8
1530	9.77	0.92	10.7	0.38	10.2
1535	9.73	1.34	11.1	1.55	11.3
1540	9.69	1.72	11.4	1.95	11.6
1545	9.64	1.97	11.6	1.20	10.8
Variation range	0.29	-	1.4	-	1.4

The entire disclosure of Japanese patent application 2002-309852 filed on October 24, 2002 including the specification, claims, drawings, and summary is incorporated herein by reference in its entirety.